LXX. THE OXIDATION OF PALMITIC ACID, BY MEANS OF HYDROGEN DIOXIDE IN THE PRESENCE OF A CUPRIC SALT.

PRELIMINARY COMMUNICATION.

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PALMITIC is probably the most commonly occurring saturated fatty acid and is one of the fatty acid constituents of lipins; yet, although in the body it must undergo oxidation with extraordinary ease, it is very resistant to the action of the usual laboratory chemical oxidising agents. Even after being heated on a water-bath for 18 hours with a concentrated alkaline solution of potassium permanganate about 40 % of the original palmitic acid was recovered. A dihydroxypalmitic acid and oxalic, succinic and adipic acids were isolated from the reaction product together with acetic, butyric and possibly capronic and caprylic acids [Gröger, 1887]. Information does not appear to be available with regard to palmitic acid but oxidation of myristic acid with strong nitric acid resulted in the formation of a mixture of dibasic acids, amongst which oxalic, succinic, adipic and suberic were identified [Nördlinger, 1886].

A small proportion of palmitic acid was shown by Dakin [1908, 1] to undergo β-ketonic oxidation when its ammonium salt was distilled with hydrogen dioxide on a boiling water-bath. About 10 % of the original acid was thus converted into carbonic acid and methyltridecylketone; the addition of a considerable excess of the dioxide produced very little further effect. Clutterbuck and Raper [1925] showed that the γ- and δ-keto-acids were formed to about the same extent as the β-acid. On further oxidation of the γ- and δ-keto-acids, succinic acid was identified in the product [Clutterbuck, 1927].

Whilst very definite evidence can be obtained that the path of oxidation of the α-amino-acids *in vivo* lies through the α-keto-acids there is no evidence that β-keto-acids are formed as the intermediate products of oxidation of the higher fatty acids. Acetoacetic and β-hydroxybutyric acids accumulate when the mechanism for the oxidation of the fatty acids is overburdened or impaired, and the available evidence points to the β-hydroxy-acid being formed by reduction of acetoacetic acid in the tissues; but these two acids are mutually convertible in the body, and the possibility of hydroxylation being the process involved cannot be excluded.

There is no evidence of the existence in the body of any ketones such as those isolated by Dakin in his experiments on the oxidation of the fatty acids *in vitro*, and if the higher β-keto-acids are so readily oxidised it is difficult to understand why a mechanism which splits the original β-keto-acid so completely into acetic acid and an acid containing two less carbon atoms than the original should cease completely to function when the stage of acetoacetic acid is reached.

The process used in the body is so perfect that no intermediate substances can be identified.

Smedley-MacLean and Pearce [1931] showed that oleic and *n*-octanoic acids were rapidly and almost completely oxidised by the action of hydrogen dioxide in the presence of a cupric salt. In the present investigation the addition of a few drops of cupric sulphate solution to one of sodium palmitate has been found to produce an equally potent effect on the oxidation of palmitic acid by hydrogen dioxide. Contrary to our expectation, palmitic was as readily oxidised as oleic acid. Indeed the behaviours of oleic and palmitic acids when heated for 3 to 4 hours at 90° with a large excess of hydrogen dioxide and a few drops of the cupric solution were very similar. About 70 % of each acid was converted into carbonic and volatile fatty acids. In the earlier stages of the oxidation of palmitic acid volatile lactones giving propionic acid on treatment with strong sulphuric acid were present. Under milder conditions of oxidation, succinic acid was isolated from both oleic and palmitic acids in about the same amounts, and in the case of oleic acid an intermediate monobasic acid, $C_8H_{14}O_4$, was obtained; from its formula this was regarded as a ketohydroxy-acid, though it was not found possible to isolate from it any well-characterised crystalline derivative. The possibility of it being an unsaturated dihydroxy-acid was not excluded and in view of our present results seems probable.

The absence of oxalic or dibasic acids other than succinic acid as intermediate products differentiates the action of hydrogen dioxide from that of other oxidising agents upon palmitic acid. The introduction of the cupric catalyst converts a process of ketonisation into one which appears to consist essentially of hydroxylation and desaturation. At the same time the breaking down of the original acid is enormously facilitated.

Traube [1905; 1906; 1910; 1911; 1932] showed that the catalytic effect of cupric salts on the oxidation of the sugars and phenols was connected with the presence of the hydroxyl group in the molecule, an observation borne out by the extraordinarily rapid oxidation of tartaric acid produced by the dioxide in the presence of a cupric salt [Battie and Smedley-MacLean, 1929].

In the present investigation, the products obtained by continuous extraction with ether of the oxidation product of palmitic acid appeared to be mixtures of isomeric substances in which unsaturated dihydroxy-acids and hydroxylactones predominate. If ketohydroxy-acids are present, they occur only in small quantity and are not the main products of the reaction.

The occurrence of unsaturated acids as oxidation products of the normal higher fatty acids does not appear to have been previously observed. Ricinoleic acid, an unsaturated monohydroxy-acid, is a constituent of castor oil and its presence shows that such an acid may be a normal product of fat metabolism, but whether the ethylene linkage arises by hydroxylation and subsequent loss of water or by dehydrogenation is not known.

From the composition of the products of successive degrees of oxidation, the hydroxyl groups in these acids are probably not adjacent but occur at intervals: their position has however not yet been determined with certainty. From a comparison of the relative numbers of the C and H atoms, as determined by analysis, with the iodine values recorded, which were always lower than the expected values, it is probable that a considerable proportion of the $\alpha\beta$-unsaturated acid was present. Crotonic and cinnamic acids, for instance, give very low iodine values [Smedley-MacLean and Thomas, 1921]. It is possible that β-hydroxylation had taken place with subsequent elimination of water giving a mixture of $\alpha\beta$- and $\beta\gamma$-unsaturated acids.

The formation of a considerable proportion of unsaturated acids as intermediate products during the oxidation of the fatty acids may indicate on the other hand a process of oxygenation which is in part at any rate one of dehydrogenation, and which may be compared with the oxidation of succinic acid in the body brought about by the succinic dehydrogenase: the succinic acid is dehydrogenated forming fumaric acid and the latter adds on water giving malic acid. It is possible that the introduction of the hydroxyl group into the palmitic chain in the presence of copper activates the hydrogen atoms attached to the neighbouring carbon atoms so that they may be removed by the action of the hydrogen dioxide. Dakin has shown that in the body cinnamic acid can arise from phenylpropionic acid and can be converted into γ-phenyl-β-hydroxypropionic acid [Dakin, 1908, 2; 1909], and that the unsaturated and saturated acids gave rise to the same product. The formation of the highly unsaturated acids containing 20 and 22 carbon atoms is also known to be effected by the liver: the identification of unsaturated acids among the oxidation products of palmitic acid in the laboratory appears to offer therefore a better analogy with the method of oxidation used in the body than does the intermediate occurrence of keto-acids.

The isolation of lactones in considerable amount showed that oxidation had taken place in the γ- or δ-position.

Succinic acid was identified at every stage of the oxidation except the earliest. This acid would itself be oxidised to a considerable extent under the conditions of the experiment, but even allowing for this the total proportion of succinic acid formed would correspond to considerably less than one molecule of succinic acid for each molecule of palmitic acid oxidised. On the whole we think that the amounts formed do not support the view that molecules of succinic acid were successively split off as groups of four carbon atoms from the palmitic chain after oxidation at the γ- or δ-carbon atom [cf. Clutterbuck, 1927] but rather that the four terminal carbon atoms had been oxidised to succinic acid.

Volatile acids of low molecular weight were formed including propionic, acetic and formic acids and lactones containing from four to seven carbon atoms; propaldehyde and acetaldehyde were identified and propionic acid as an oxidation product of the volatile lactones. The results obtained appeared to support the view that volatile fatty acids of low molecular weight and their hydroxy-derivatives were split off from the long carbon chain.

Whatever may be the mechanism involved, oxidation by means of hydrogen dioxide in the presence of a cupric salt through intermediate stages of desaturation and hydroxylation certainly appears to be the most effective laboratory process by which the higher fatty acids may be broken down to carbonic acid and the lower fatty acids, and suggests that some such process may be involved in oxidation *in vivo*.

Method of experiment.

2 g. palmitic acid were heated at 90° with the calculated amount of N NaOH solution and with 15 ml. of a 2·73 % solution of crystallised copper sulphate, 212 ml. water and such an amount of N NaOH as was found necessary to neutralise the amount of 20 vol. H_2O_2 solution to be added gradually during the experiment. The flask was fitted with a dropping funnel and with a reflux condenser from which a tube led to a series of flasks containing $N/2$ baryta solution. At the end of the specified time, an amount of N sulphuric acid exactly equivalent to the N NaOH originally taken was added and the flask cooled,

whilst air freed from carbon dioxide was drawn through the apparatus. After filtering off any insoluble residue a measured quantity of N alkali was added to destroy the dioxide, and when this had been accomplished, the equivalent quantity of N H_2SO_4 was added, the liquid concentrated either by steam-distillation or *in vacuo* and the residual liquid continuously extracted with ether. The distillate was neutralised with N NaOH, the first part of the neutral distillate collected and examined for neutral substances and the residue taken to dryness. The average molecular weight of the volatile acids was calculated from the amount of N NaOH solution used for neutralisation and the weight of dry sodium salts.

EXPERIMENTAL RESULTS.

In a series of preliminary experiments, the reaction mixture was heated at 60° for $3\frac{1}{2}$ hours with a large excess of hydrogen dioxide: about 80 % of the original palmitic acid was recovered unchanged; the 20 % which had disappeared had been converted into carbonic acid (8 % total carbon), volatile acids (8 %) and the remainder into a mixture of ether-soluble substances from which succinic acid was isolated. There were indications of the presence of an acid of high molecular weight giving a crystalline dinitrophenylhydrazone of unsharp melting-point and also of reducing substances. A water-soluble acid was present giving the iodoform reaction in the cold. There was however no evidence of the presence of methyltridecylketone such as would have been expected if β-keto-oxidation

Table I.

2 g. palmitic acid heated with H_2O_2 and Cu salt at 90°.

	Minutes heated	ml. 6 % H_2O_2	Wt. Cu palmitate and palmitic acid g.	Total wt. CO_2 g.	Wt. Na salt of volatile acids g.	Av. mol. wt. of volatile acids	% volatile reducing acid calculated as formic*	Total wt. of ether extract g.	Wt. of succinic acid g.
			Volatile acids separated by steam-distillation.						
A.	11	50	1·29	0·37	0·28	75	10·1	0·44	Negative
	20	75	1·34	0·37	0·28	75	10·1	0·44	Negative
B.	20	110	0·40	0·42	0·90	84	12·75	1·25	Positive
	15	80	0·23	0·47	0·85	78	12·29	>0·55	Positive
C.	60	175	0·21	0·68	1·02	74	18·6	1·6	0·1
	60	175	0·04	0·89	1·11	74	18·3	1·22	0·1
	60	200	0·30	0·79	1·08	63	13·15	1·21	—
	60	200	—	1·21	1·31	56	15·3	1·34	—
			Volatile acids separated by concentration *in vacuo*.						
D.	60†	175	0·16	—	0·33	67	23·8	{0·1 neutral, 0·8 acid}	0·1
	60	175	0·29	—	0·52	68	34·0	1·2	0·1
	60†	175	0·30	—	0·47	—	33·0	1·0	0·05
	60†	175	0·32	—	0·60	73	—	0·81	0·11
	60	175	0·19	—	—	51	24·3	—	—
	60†	175	0·25	—	1·25	131	10·7	0·90	>0·1
	60	175	0·15	0·72	0·43	64	—	—	—
			Volatile acids separated by steam-distillation.						
E.	120	185	0·40	1·49	1·20	64	14·0	1·2	—
	120	285	—	1·49	1·20	54	5·6	—	—
F.	240	285	0·10	2·81	1·30	117	3·5	0·30	—
	240	285	0·0	2·9	1·08	53	3·8	0·17	—

* The reducing power was estimated by the reduction of mercuric chloride to calomel and calculated for purposes of comparison, but since formic acid is largely converted into CO_2 under the conditions of the experiment, other volatile reducing acids may have been present.

† In each of these experiments larger quantities of palmitic acid were oxidised and the amount of product calculated as derived from 2 g. of palmitic acid.

had taken place, as is known in the absence of the cupric catalyst. The further experiments were carried out at 90° at which temperature practically all the palmitic acid was oxidised.

After heating for 10–20 minutes at 90° with a limited amount of hydrogen dioxide, carbonic acid was evolved, and if the experiment was stopped while a considerable amount of the bluish insoluble precipitate which had separated remained, about 2/3 of the original palmitic acid was recovered, part of it as copper palmitate. About 7 % of the total carbon had been converted into carbonic acid, about 5 % into volatile acids and the remaining 8 % was present in the ethereal extract. The residue from the latter was neutralised and the solution extracted with ether to remove any neutral substances. The oil obtained from this neutral fraction contained 66·78 % C and 10·14 % H. It appeared to be a mixture of lactones corresponding approximately with the formula $C_8H_{14}O_2$ which requires C, 67·61; H, 9·86 %.

The behaviour on titration of the oil obtained from the acid fraction after it had been dried to constant weight in a vacuum-desiccator suggested the presence of a lactonic acid, since the colour of the indicator repeatedly disappeared on warming with additional quantities of $N/10$ NaOH. (Found for the free acid (micro-analysis) C, 64·13; H, 9·64 %. Mol. wt. by titration, 224 to 260; from analysis of Ag salt, 244. $C_{13}H_{24}O_4$ requires C, 63·93; H, 9·84 %. Mol. wt. 244.) Attempts to prepare a crystalline derivative from this acid were unsuccessful, and no evidence of the presence of the keto-group was obtained. A reducing group was present, since when warmed for a considerable time with ammoniacal silver nitrate solution a good silver mirror was deposited.

When the acid was warmed for one hour on a boiling water-bath with 50 % sulphuric acid, a strong gorse-like smell, characteristic of fatty lactones was developed, and a very small amount of a neutral substance containing 70·40 % C and 10·40 % H was isolated agreeing with the theoretical values for the lactone $C_{10}H_{18}O_2$ (70·59 % C; 10·59 % H).

From its behaviour on titration it appeared that the fraction having the composition $C_{13}H_{24}O_4$ contained a certain percentage of lactone but that most of it consisted of free acid, the proportions of carbon and hydrogen agreeing with those required by a ketohydroxy-acid. Since however the keto-group was not detected and could certainly not have been there to any large extent, it seemed probable that the bulk of this product was an unsaturated dihydroxy-acid. The substance reduced permanganate in neutral solution. At this stage no succinic acid was detected.

The formation of a product agreeing with the composition $C_{13}H_{24}O_4$ makes it probable that not only had γ- or δ-hydroxylation of the original C_{16} acid taken place but that hydroxylation had also taken place at two or three other points of the chain. The unsaturated linkage present in the C_{13} product may indicate that hydroxylation of the atom in the β-position to the 13th carbon atom had occurred with subsequent elimination of water, and the presence of a lactone that either the γ- or δ-carbon atom had been hydroxylated. Since, after heating with sulphuric acid, the lactone isolated had the composition $C_{10}H_{18}O_2$, it is possible that the remaining OH-group was in the γ- or δ-position to the 13th carbon atom.

When the proportion of hydrogen dioxide was increased, a point was reached at which rapid solution of nearly all the precipitate floating on the surface of the reaction mixture occurred, and practically the whole of the palmitic acid had been converted into water-soluble products. At this stage the quantity of carbonic acid given off was only slightly increased, but the amount of volatile

acids separating on steam-distillation was very much greater, and the average molecular weight showed that acids of higher molecular weight than acetic acid were present (*cf.* Table I). The residue from the ether extract was much increased, and its behaviour on titration again showed that a lactonic acid was present. Crystals of succinic acid were isolated and identified by a mixed melting-point.

When the reaction product was heated with a considerable excess of hydrogen dioxide for one hour, the quantities of carbonic and volatile acids produced were increased, but the average molecular weight of the latter was diminished. When the product was concentrated by distillation *in vacuo*, the total weight of volatile acids was less than half of that obtained when the volatile acids were separated by steam-distillation, and the proportion of a reducing volatile acid was much higher. The ether extract of the product obtained after the residue had been concentrated *in vacuo* smelt of acetic acid and only reached constant weight after long evacuation in a vacuum desiccator. The difference shown in the amount of volatile acids obtained by the two different methods of working up (*cf.* Table I) may be reckoned as due to the incomplete separation of the volatile acids, since during the concentration *in vacuo*, the product was not taken to complete dryness. In one experiment, the volatile distillate was neutralised with NaOH solution and extracted with ether. (Found (micro-analysis) C, 54·71; H, 8·97 %. $C_6H_{12}O_3$ requires C, 54·54; H, 9·09 %.) The amount was very small and no evidence as to structure was obtained.

In another experiment the sodium salts of the volatile acids were treated with strong H_2SO_4, and the diluted product was extracted with ether. The ethereal layer was shaken with potassium carbonate solution and the alkaline aqueous layer acidified and extracted with ether. From this ethereal solution an oil was obtained. (Found C, 43·99; H, 1·63 %. Mol. wt., by titration, 108; by analysis of Ag salt, 95. $C_4H_8O_3$ requires C, 46·15; H, 1·69 %. Mol. wt. 104.) From the neutral ethereal layer separated from the potassium carbonate solution, a substance of characteristic lactone odour was separated. (Found C, 64·53; H, 9·81 %. $C_6H_{10}O_2$ requires C, 63·16; H, 8·77 %. $C_7H_{12}O_2$ requires C, 65·63; H, 9·38 %.) Volatile hydroxy-acids and lactones had therefore been formed as decomposition products.

In the neutral volatile portion (obtained by redistilling the neutralised distillate, which had been separated either by steam-distillation or by concentration under diminished pressure), propaldehyde was identified by means of its orange-red dinitrophenylhydrazone, melting after recrystallisation from alcohol at 153–154° and the result was confirmed by analysis of the hydrazone. (Found N, 24·05 %. $C_9H_8N_4O_4$ requires N, 23·73 %.)

After oxidising the volatile acids with chromic acid, a neutral product giving analytical figures between those required for the lactones $C_6H_{10}O_3$ and $C_7H_{12}O_3$ was obtained. When the sodium salts of the volatile acids were treated with strong sulphuric acid and the product distilled, propionic acid was identified in the distillate and separated as the characteristic basic lead salt. The routine method for estimating formic acid by reduction of mercuric chloride was also applied to the mixture of volatile acids and very considerable reduction took place. Since however formic acid is readily destroyed under the conditions of the experiment, some other reducing volatile acid may have been present.

After one hour's heating, for every 2 g. of palmitic acid oxidised, between 0·1 and 0·2 g. succinic acid was isolated as crystals from the mixture, but there was evidence that considerably more was formed.

The residue from the ethereal extract was divided into two parts by means

of its solubility in benzene. In one experiment in which 24 g. of palmitic acid had been oxidised, 6·72 g. of an oil insoluble in benzene and 4·6 g. of one soluble in benzene were obtained.

From the oil insoluble in benzene more than 1 g. of succinic acid separated as crystals and the residue was divided into two fractions: (1) a part soluble in water of low average molecular weight (94 by silver salt analysis, 122 by titration) containing a considerable amount of succinic acid and giving a silver salt which rapidly darkened; (2) a part insoluble in water. The latter had an average molecular weight of 167, determined by titration and apparently contained about 20 % lactone. (Found C, 53·74; H, 7·87 %.) Its iodine value was 22·4. The simplest formula agreed most nearly with $C_7H_{12}O_4$, which requires C, 52·50; H, 7·50 %. Since the proportion of carbonyl group determined by its reaction with sulphite was negligible, and considering the proportion of carbon to hydrogen atoms, unsaturated hydroxy-acids must have been present with a small proportion of hydroxylactone.

The composition of the water-soluble fraction (1) varied in different experiments from C, 52·7 to 56·5; H, 7·1 to 7·5 %, and it contained an appreciable amount of succinic acid. Estimation of the carbonyl group showed that less than 2 % was present; the iodine value was 35, indicating a considerable proportion of unsaturated acid in the mixture.

The composition of the fraction soluble in benzene varied in a number of different experiments from 58·44 to 65·69 % C and from 7·8 to 9·7 % H. The molecular weight determined by titration gave values from 150 to 200 and the product contained about 21 % lactone. The product was divided into neutral and acid fractions.

The neutral product appeared to consist of a mixture of hydroxylactones for the separation of which neither distillation nor fractionation by means of solvents has yet given satisfactory results. A fraction insoluble in light petroleum contained 63·00 % C and 8·08 % H. Its molecular weight (determined by heating a known weight for one hour on a water-bath dissolved in alcohol with a known amount of NaOH and titrating the excess) gave a molecular weight of 174, but the end-point was not very satisfactory. This substance did not react with a solution of sodium bisulphite and was therefore free from any appreciable amount of keto-compound. Its iodine value was 68, corresponding with the existence of rather less than half an ethylene linkage for the observed molecular weight. As already pointed out an ethylene linkage in the $\alpha\beta$-position gives a very low iodine value. The available evidence would point to the presence of the lactone of an unsaturated hydroxy-acid corresponding approximately with the formula $C_9H_{14}O_3$, which requires C, 63·53; H, 8·23 %. Mol. wt. 170. Until a better method of separation and identification has been found a definite formula cannot be ascribed to it.

The acid fraction was converted into sodium salts, the solution of which was evaporated to dryness and the dry salts fractionated by their solubility in 96 % alcohol and acetone. The acid derived from a very hygroscopic sodium salt soluble in alcohol and not precipitated from alcoholic solution by the addition of acetone agreed in composition with the formula $C_{10}H_{18}O_4$. (Found C, 59·58; H, 8·39 %. Mol. wt. by titration 200, 203. $C_{10}H_{18}O_4$ requires C, 59·40; H, 8·91 %. Mol. wt. 202.) It no longer reacted as a lactonic acid, and the estimation of the carbonyl group was negative. The I.V. was 16·5. It may therefore be regarded as a dihydroxydecenoic acid.

For purposes of reference we synthesised the α-keto-derivatives of octanoic, nonanoic and decanoic acids and examined their properties. The method adopted

was that used by Bouveault and Locquin [1904], in which nitrosylsulphuric acid was allowed to act upon the ethyl ester of the α-acetyl derivative of the normal fatty acid in the presence of concentrated sulphuric acid, when the acetyl group was replaced by the group —NOH. By the further action of nitrosylsulphuric acid in the presence of formic acid the corresponding α-keto-acid was obtained.

Preparation and properties of α-keto-octanoic acid.

The ethyl ester of α-acetyloctanoic acid was prepared by heating together equimolecular proportions of sodium ethoxide, ethyl acetoacetate and hexyl iodide. The oxime of this ester (M.P. 52–53°) was prepared and, after recrystallisation, converted into α-keto-octanoic acid [Bouveault and Locquin, 1904; Blaise and Luttringer, 1905]. This was a colourless crystalline substance, smelling strongly of "goat," which melted at 117–118° after recrystallisation from alcohol and subsequent washing with light petroleum, in which it was sparingly soluble. It formed an oxime, M.P. 110°, and a bright yellow dinitrophenylhydrazone which, after two recrystallisations from alcohol, melted at 136·5–137·5°. The acid gave a silver mirror on warming with ammoniacal silver nitrate. (Found: C, 60·28; H, 8·76 %. Theoretical: C, 60·76; H, 8·86 %.)

Preparation and properties of α-ketononanoic and α-ketodecanoic acids.

These acids were prepared in a similar manner. α-Ketononanoic acid was derived from the ethyl ester of α-acetylnonanoic acid [Jourdan, 1880]; the oxime was a white crystalline substance melting at 58–59° after recrystallisation from dilute acetic acid. α-Ketononanoic acid melted at 105–106°, formed an oxime melting at 112°, and a dinitrophenylhydrazone melting at 129°. It reduced ammoniacal silver nitrate. (Found: C, 62·26; H, 9·08 %. Theoretical: C, 62·78; H, 9·30 %.) α-Ketodecanoic acid was prepared from ethyl α-acetyldecanoate [Guthzeit, 1880]; the oxime melted at 60–61°. The α-keto-acid melted at 85–86° after recrystallisation from light petroleum. It gave a dinitrophenylhydrazone, M.P. 126–128°, and a silver mirror with ammoniacal silver nitrate. (Found: C, 64·16; H, 10·15 %. Theoretical: C, 64·51; H, 9·68 %.)

SUMMARY.

Although we have not yet been able to characterise substances of undoubted chemical individuality from the complex mixture of ether-soluble products obtained on oxidising palmitic acid by means of hydrogen dioxide in the presence of a cupric salt, certain inferences as to the nature of the products and therefore as to the intermediate stages of the process can be made.

1. Hydroxylation appeared to take place simultaneously at several points of the palmitic chain.

2. The palmitic carbon chain was gradually broken down, and evidence of the formation of unsaturated hydroxy-acids containing ten carbon atoms was obtained. There was also some indication that chains containing respectively thirteen and seven carbon atoms were formed during the reaction, but the chemical individuality of these substances requires further confirmation.

3. Ketonic acids were present, if at all, only in very small quantities and were certainly not the main product of oxidation.

4. Lactones, indicating the formation of γ- or δ-hydroxy-acids were split off during the course of the reaction.

5. Unsaturated hydroxy-acids were present and, from the analyses of the products, these formed the main bulk of the intermediate substances. The low

iodine values recorded probably indicated the presence of some unsaturation in the 1:2-position.

6. Volatile acids of low molecular weight were formed in considerable quantity and were split off at an early stage.

7. When heated for 4 hours at 90° more than 50 % of the total carbon of the palmitic acid appeared as CO_2 and more than 20 % as volatile acids.

8. For purposes of reference the α-ketoheptanoic and α-keto-octanoic acids were prepared and characterised.

The study of these intermediate compounds is in progress and the result will form the subject of a further communication.

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